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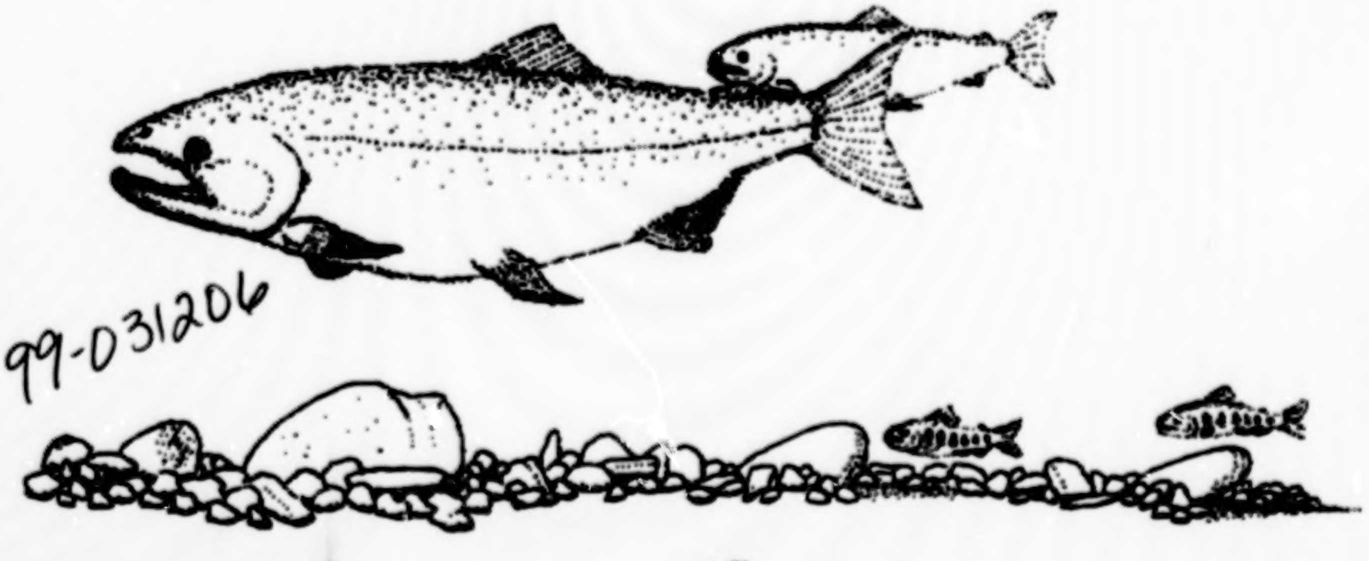
U.S. Fish & Wildlife Service

Seasonal Fish Densities Near River Banks Treated With Various Stabilization Methods

First Year Report of the Flood Technical Assistance Project

Western Washington Office
Aquatic Resources Division

Lacey, Washington
December 1998



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Seasonal Fish Densities Near River Banks Stabilized with Various Stabilization Methods

First Year Report of the Flood Technical Assistance Project

by

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Abstract.- This report describes results obtained from data collected during the first year of a two-year study to determine which methods of river bank stabilization are most commonly used for flood protection in western Washington and the impacts/benefits of these methods to fish densities.

We also examined the influence of different habitat variables on fish densities. We mailed a survey to agencies and organizations involved with bank stabilization and received documentation of 667 river bank stabilization projects in western Washington. Riprap (414 of 667) and riprap with deflectors (82 of 667) were the most common methods used to stabilize river banks in western Washington. Methods commonly considered fish-and-wildlife friendly, such as bioengineering (16 of 667) and large woody debris (13 of 667), were rarely used.

Using survey results, we selected five types of bank treatments to further evaluate their impacts/benefits to fish. We examined seasonal fish densities at streambanks stabilized using riprap, riprap with large woody debris (LWD) incorporated into the project, rock deflectors, rock deflectors with LWD (combination projects), and LWD. LWD-stabilized sites were the only project types that consistently had greater fish densities than their control areas during spring, summer, and winter surveys. Riprap sites consistently had lower fish densities than their control sites during all surveys. Fish densities were generally lower at deflector sites than their controls during the spring and summer, but greater during the winter. Although large differences (between stabilized sites and controls) existed in some cases, the differences were rarely statistically significant due to high variation and small sample size.

Instream LWD cover and overhead riparian cover were the habitat variables that most consistently influenced fish densities at stabilized and control sites we surveyed. Fish densities were generally positively correlated with increasing surface area of LWD and increased overhead riparian cover within 30 cm of the water surface.

We recommend using LWD cover when possible, based on these preliminary findings. LWD incorporated into riprap and rock deflectors needs to be larger and provide more complex cover than what is currently used.

A final report describing results of both years of this research will be completed during the summer of 1999.

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Introduction

Recent floods have resulted in extensive damage to river banks throughout western Washington and the Pacific Northwest. This has lead to significant efforts to stabilize eroding or destabilized stream banks. Streambanks have historically been repaired using riprap. However, studies have indicated that juvenile salmonid densities (Knudsen and Dilley 1987) and species diversity (Li et al. 1984) are reduced near riprap banks compared to natural banks. This has led many natural resource agencies to recommend the use of "environmentally friendly" methods of bank stabilization. These methods include tree revetments, large woody debris or rootwad incorporated into riprap, willow stakes, or other bioengineering methods as alternatives to riprap. However, the actual benefits of these activities to aquatic ecosystems have not been evaluated.

Field evaluations have shown that stabilized banks reduce habitat quality for juvenile salmonids (Li et al. 1984; Knudsen and Dilley 1987) and that different methods of bank stabilization influence fish abundance differently (Li et al. 1984; Lister et al. 1995). Knudsen and Dilley (1987) found that flood-control construction activities affected summer and fall salmonid carrying capacities differently and were dependent upon stream size, size of juvenile salmonids, and severity of habitat alterations. Li et al. (1984) observed greater larval and juvenile fish diversity and density near spur-dikes than continuous rock revetments. However, larval fish diversity and densities near spur-dikes were intermediate in value between natural banks and rock revetments. Juvenile salmonid abundance also varied at riprap sites treated with different sized rock (Lister et al. 1995).

The objectives of this study were to: 1) document the types of river bank stabilization projects most commonly used in western Washington; 2) determine which bank stabilization methods support the greatest fish densities; and 3) determine which physical habitat features influence fish densities.

Study Area

This study was conducted in several different rivers of western Washington (Figure 1, Table 1). We completed snorkel surveys at 67 sites in these rivers. The number of sites per river ranged from two to eight. Descriptive information for each river and location of study sites are presented in Table 1.

Western Washington consists of five physiographic regions: the Olympic Mountains, Willipa Hills, Puget Lowlands, South Cascades, and North Cascades (Lasmanis 1991). We had study sites in rivers in each of these physiographic regions. Climate conditions, with respect to rainfall, vary widely among these physiographic regions and within these regions. For example, the Puget Lowlands receives approximately 125 cm of rain annually, while areas of the Olympic Mountains receive over 300 cm rain annually. Areas of the northern slopes of the Olympic Mountains receive less than 50 cm of rain annually. The Cascade Mountains (200 cm) and Willipa Hills (250 cm) are intermediate with respect to rainfall.

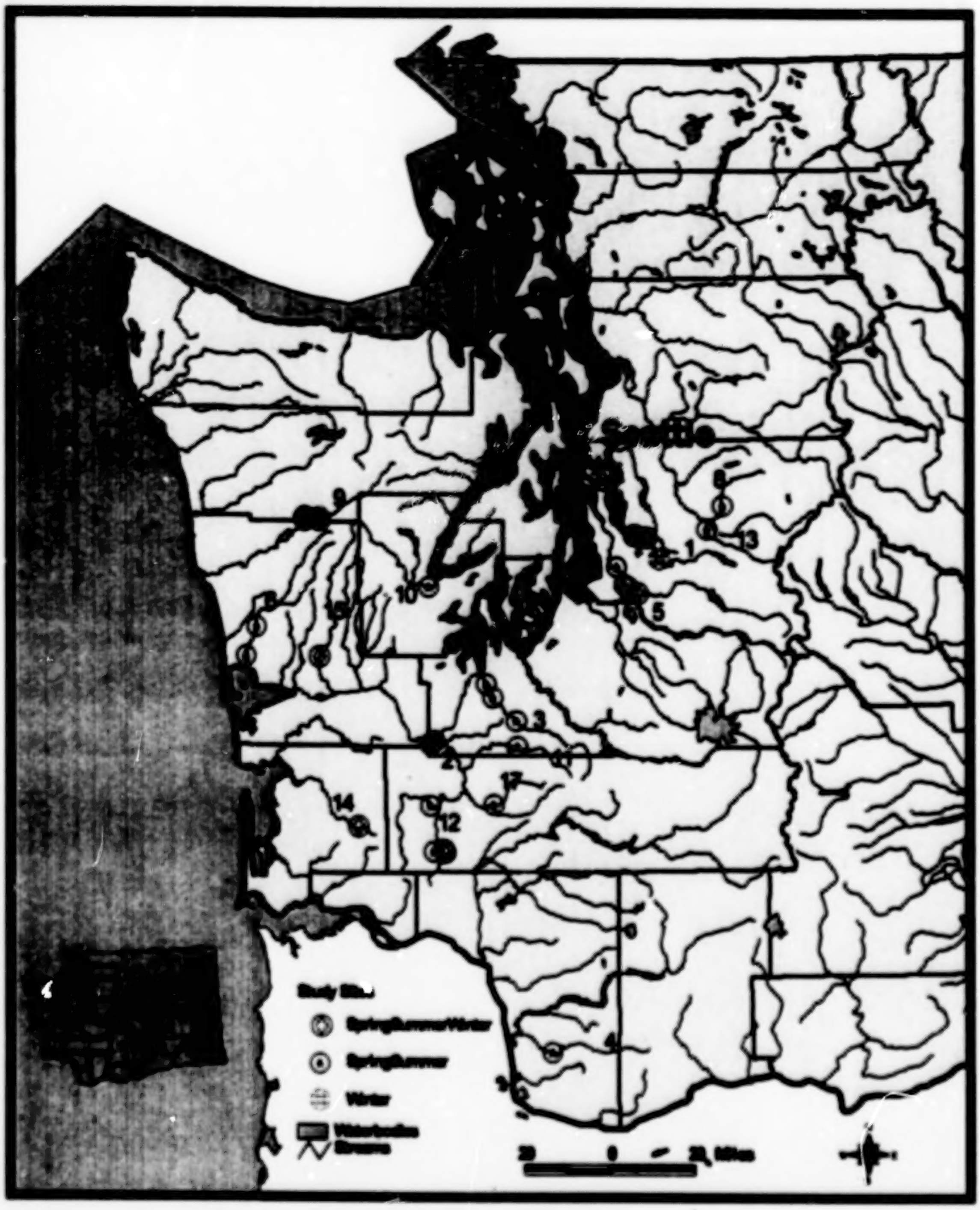

Figure 1. Location of bank stabilization projects evaluated during this study. See Table 1 for descriptive information about study sites. Numbers refer to river systems as described in Table 1.

Table 1. Descriptive information for each river in which a study site was located (Source: Phinney and Bucknell 1975; Williams et al. 1975; Wiggens et al. 1995) (nd = no published data available).

River	River No. (Fig. 1)	Length (Km)	Project location (River Km)	Drainage area (km^2)	Mean discharge (m^3/s)	Land use upstream	Physiographic regions drained
Cedar	1	93.3	7.2 7.7 9.3 13.3	486	10.62	Urban	Cascades North
Chehalis	2	204	82.1 85.3 86.9 146.5 146.7	17,441	78.22	Rural-Residential Agriculture	Willapa Hills Cascades South Olympic Mts.
Deschutes	3	84	7.2 16.5 32.6	420	7.33	Urban/ Private Forestry	Cascades South Puget Lowlands
E.F. Lewis	4	70	23.0	234	nd	Rural-Residential Agriculture	Cascades South
Green	5	150.6	41.0 50.3 52.3 57.7	1,033	37.1	Urban- Rural/ Forestry	Cascades North
Humptulips	6	98.2	8.8 28.2	337	nd	Private Forestry	Olympic Mts.
N.F. Newaukum	7	31.2	1.6	83	13.8	Agriculture	Cascades South
N.F. Snoqualmie	8	41.8	1.3	166	14	Forest (Public)/ Agriculture	Cascades North

Table 1.   Continued.

River	River No. (Fig. 1)	Length (Km)	Project location (River Km)	Drainage area (km^2)	Mean discharge (m^3/s)	Land use upstream	Physiographic regions drained
Quinault	9	110.7	73.1 73.2 73.5	684	80.1	National Park /Forest	Olympic Mts.
Skokomish	10	67.4	6.1	588	14.2	Forestry	Olympic Mts.
Skookumchuck	11	64.7	34.6	290	9.5	Forestry Agriculture	Cascades South
S.F. Chehalis	12	45.7	8.9 25.1 25.4 26.1	124	nd	Agriculture	Willapa Hills
S.F. Snoqualmie	13	49.6	4.0	212	15.3	Forest (Public)/ Agriculture	Cascades North Puget Lowlands
Willipa	14	71.8	62.7 62.8	337	17.6	Forestry/ Agriculture	Willapa Hills
Wynoochee	15	101.8	22.0 22.1	401	34.1	Forestry/ Agriculture	Olympic Mts.

Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead (*O. mykiss*), and cutthroat trout (*O. clarki*) were present in all the systems that we surveyed. Sockeye salmon (*O. nerka*) were present only in the Quinault and Cedar Rivers. We observed chum salmon (*O. keta*) only in the Dosewallips River. Mountain whitefish (*Prosopium williamsoni*) and speckled dace (*Rhinichthys osculus*) were found in all the systems we surveyed. Redsided shiners (*Richardsonius balteatus*) were absent from the Cedar, Green, N.F. Snoqualmie, S.F. Snoqualmie, Quinault, Skokomish, Skookumchuck, and Willipa sites. Northern squawfish (*Ptychocheilus oregonensis*) were present in the Chehalis, S.F. Chehalis, Wynoochee, and E.F. Lewis Rivers. Bull trout (*Salvelinus confluentus*) were observed only in the Quinault and Skokomish Rivers. Sculpins (*Cottus sp.*) and suckers (*Catostomus sp.*) were found in all the systems we surveyed. A number of introduced species were also present in the Chehalis River, including pumpkinseed (*Lepomis gibbosus*), largemouth bass (*Micropterus salmoides*), and rock bass (*Ambloplites rupestris*). Rock bass were also observed in the Deschutes and Cedar Rivers.

Methods

Bank Stabilization Methods

We determined the most common methods used to stabilize streambanks in western Washington by mailing a questionnaire to local agencies. We mailed 78 questionnaires (Appendix A) to individuals and organizations involved with bank stabilization, including the Natural Resources Conservation Service (NRCS), Army Corps of Engineers (COE), Federal Emergency Management Agency (FEMA), tribes, state agencies, county public works departments, and conservation districts. The questionnaire requested lists and locations of bank stabilization projects, including purpose, project length, installation date, type of project, and success/failure of the project (Appendix A). We then summarized these data to see which methods were used most often and determined the total length of stream banks stabilized using each method.

Fish Densities at Natural and Stabilized Stream Banks

Experimental Design.-There are a number of different bank stabilization methods used in western Washington rivers and no single project is identical to another project. However, these methods can be grouped based on their physical form. We grouped the projects we evaluated into the following five major classifications:

Riprap: A layer of rock (generally angular) placed over an eroding bank

Riprap with LWD (RRLWD): A layer of rock (generally angular) placed over an eroding bank with LWD or rootwads buried in the rock or cabled to the rock.

Rock deflectors (deflectors): Rock structures that are keyed to one bank and project into the flow. They direct flow of water toward the middle of the river.

Woody debris (LWD): A layer of LWD, either buried in or cabled to the bank, placed along an eroding bank.

Rock deflectors with LWD (combination): Rock structures keyed to one bank and projecting into the flow with LWD buried in the deflector or cabled between deflectors.

The experimental design for this study was complicated by the fact that many different rivers, with potentially different fish communities and seeding levels, were required to obtain the desired sample size. In order to account for these differences, each stabilized site (bank stabilization site) had an associated control within the same river. The controls were naturally stable areas (banks) that were as similar to the stabilized site as possible in length, channel form (straight, curve), mesohabitat type (pool, glide, riffle), and proportions of mesohabitats.

We then completed two distinct and separate analyses of the data we collected. First, we tested the hypothesis that fish densities at each type of stabilized bank were not significantly different from those at their control sites using a paired t-test. Second, we used Analysis of Variance (ANOVA) and Tukeys multiple comparisons (Zar 1984) to test the hypothesis that the differences in fish densities at stabilized sites and their control areas were not significantly different among the different bank stabilization methods we examined. We calculated the difference in fish density between bank stabilization and their associated control sites as follows:

$$D_d = D_s - D_c$$

Where D_d is the difference in density between a stabilized site (D_s) and its control site (D_c). We considered differences significant at an alpha level of 0.10. We used this conservative alpha level due to the small sample size and high variability of the data. These two factors resulted in low statistical power and an increased likelihood of not rejecting a false null hypothesis that no differences in fish densities existed.

We transformed the data prior to analysis using a square root transformation (Zar 1984) to attain normality and control for variances. The distribution of calculated differences between stabilized sites and their controls varied significantly from normal for most species (Shipiro-Wilk Statistic: P=0.0001-0.03). Only the data for 2+ trout (Shipiro-Wilk: P=0.74) and zero-age trout (Shipiro-Wilk: P=0.18) during the spring, and redsided shiners (Shipiro-Wilk: P=0.91) and 2+ trout (Shipiro-Wilk: P=0.10) during the summer did not vary significantly from a normal distribution. The distribution of fish densities for all sites varied significantly from normal (Shipiro-Wilk Statistic: P=0.0001).

We surveyed seven sites treated with each different bank stabilization method during the spring and summer. During the winter we surveyed four replicates of combination, RRLWD, and LWD-stabilized sites, and three deflector and riprap sites. Sample sizes were reduced during the winter due to time constraints. Poor weather kept us from completing surveys during much of January, February, and March, and we felt that April 1 was the latest we could survey and consider the data as winter surveys.

Some locations (both controls and bank stabilization sites) lacked fish of certain species, which would artificially reduce mean differences between project sites and their controls. To eliminate this potential bias, we removed all sampling locations that lacked the species of interest at both the project site and its control prior to analysis. For example, if coho salmon were absent from one project site and its control, the sample size for that bank stabilization method would be 6 rather than 7. Thus, the sample sizes presented in the results represent the sites that actually had that fish species rather than the number of sites we surveyed.

Our conclusions relied on the assumption that fish densities at our control areas represented mean fish densities for the reach in which the stabilized site was located. We tested this assumption by comparing fish densities at our controls to a second control area (test control) within the reach. This was completed at seven different locations. The test control was similar to the original control site and consisted of natural stream areas with naturally stable banks. Data were collected at each location using the same procedures used at the stabilized sites and their representative controls. We tested the hypothesis that fish densities at the controls and test controls were equal using a paired t-test (Zar 1984).

Fish Densities.-Fish abundances were estimated during the spring (12 June, 1997 to 17 July, 1997), summer (8 August, 1997 to 16 September, 1997), and winter (9 February, 1998 to 1 April, 1998) by snorkeling. Spring and summer snorkel surveys were completed during the day and winter surveys were completed at night. Day surveys were conducted from 2 hr after sunrise to 2 hr before sunset to ensure light levels were adequate. Night surveys were completed from 1 hr after sunset to 1 hr before sunrise. We completed winter surveys at night because the literature suggests that many fish (especially salmonids) hide during the day and emerge at night during the winter (Heggenes et al. 1993; Riehle and Griffith 1993; Contor and Griffith 1995). These accounts were supported by cursory data that we collected during this project (Appendix B).

Two (spring) or three (summer, winter) snorkelers estimated fish abundance at each site. Snorkelers entered the water downstream of the site to be sampled and moved slowly upstream counting fish. All salmonids (coho, chinook, steelhead, cutthroat, bull trout, and whitefish) adjacent to the stabilized bank were identified to species when possible, and counted. Counts of steelhead and cutthroat (trout) were combined due to difficulty differentiating the two species during snorkeling. Trout lengths were estimated visually by the snorkelers and divided into four length classes: zero-age trout (0-50 mm fork length), 1+ trout (50-100 mm fork length), 2+ trout (100-200 mm fork length) and 200+ trout (> 200 mm fork length). Counts were recorded for each of these different length classes. Counts of age 1+ trout (50-100 mm fork length) and coho pre-smolts (pre-smolts) were combined during the winter into a class called pre-smolts due to difficult in distinguishing the groups at night. Salmonid fry also were combined into one group during winter night surveys for the same reason. A high proportion of the fish would generally move away from the light before we could get close enough for positive identification. Non-salmonids were identified to species when possible or to family and counted. Counts were recorded on underwater slates strapped to the divers' arms during snorkeling and transferred to field data sheets once the area was completely surveyed.

The estimate of fish abundance was the higher of two counts during the spring surveys. However, the bounded-count methodology (Regier and Robson 1967) was used on subsequent surveys. Three snorkelers estimated fish abundance at each site for bounded counts. The estimated fish abundance was calculated as follows:

$$N = 2N_m - N_{m-1} \qquad \text{(Regier and Robson 1967)}$$

where N is the estimate of fish abundance, N_m is the largest count, and N_{m-1} is the second largest count. Fish abundance estimates were converted to densities (fish/km) by dividing fish abundance estimates by project length since project sites and their controls were not always the same length.

Fish Densities and Habitat Relationships

Habitat Measurements.-We measured habitat conditions at each site where snorkel surveys were completed. These data were collected to see how habitat conditions differed at stabilized sites and their controls, and to evaluate the influence of individual habitat variables on observed fish densities. The percent of the area with overhead riparian cover was estimated visually. The primary river habitat(s) adjacent to the bank stabilization site were classified as pools, glides, runs, or riffles following Bisson et al. (1982) and Helm (1985). Primary habitats were those habitat units that generally encompassed the entire channel width. Pools were further classified as lateral scour, straight scour, or backwater pool following Bisson et al. (1982). We also noted secondary habitats adjacent to the study site. Secondary habitats were defined as habitat units that extended from one-fifth to one-half the wetted channel width. Secondary habitats were classified using the same classifications as primary habitats. We measured the length, average width, average and maximum depth, average current velocity, and also noted percent dominant and subdominant substrates, substrate embeddedness, percent vegetation overhang (riparian cover within 30 cm of the water surface), and instream woody debris for each secondary habitat.

Length and width measurements were recorded using a laser rangefinder and/or stadia rod. Depths were measured using a stadia rod and current velocities were measured using a Swouffer Model 2100 current meter. Substrate composition was recorded by the divers during the snorkel surveys. We recorded the size and percent of the dominant and subdominant substrates visually based on Cummins (1962) (Table 2). Embeddedness was estimated visually as <5%, 5-25%, 25-50%, 50-75%, and 75-100%.

Table 2. Substrate classifications used for this study (Cummins 1962).

Substrate	Description/particle size range (mm)
Silt/Sand	0.0039-2
Gravel	2-64
Cobble	64-265
Boulder	>256
Bedrock Hardpan	Exposed underlying rock not distinguishable as a boulder
Debris	Bottom covered with terrestrial debris such as leaf litter and/or small woody debris

Woody debris at the project site was counted, classified by type, measured for length and width, and visually classified with regard to complexity. Woody debris accumulations were classified as log, tree, log jam, rootwad, or small woody debris. The length and diameter of the trunk and its associated rootwad were measured separately for those debris structures classified as rootwads. The complexity of rearing cover provided by the structure was classified visually as sparse, medium, and dense. Single logs were classified as sparse, logs with some branches as medium, and complex log jams, rootwads, or trees were classified as dense.

We compared individual physical habitat variables at the bank stabilization sites and their controls using a paired t-test for each stabilization method we evaluated. We also tested how habitat variables influenced fish densities using simple linear regression. These comparisons were completed using weighted mean values from the secondary habitats. The values were weighted based on the length of each secondary habitat unit relative to the length of the entire area surveyed. We completed two comparisons of the influence of habitat variables on fish densities. First, we calculated differences in weighted means of each habitat variable between stabilized sites and their controls (stabilized sites - controls). We regressed the differences in each weighted mean habitat variable against observed differences in fish densities. Second, we regressed weighted mean of each habitat variable for each site surveyed (controls and stabilized sites) against fish densities observed at each site (stabilized sites and controls).

Results

Bank Stabilization

We received 27 responses to our mailed questionnaire, which resulted in 667 reported bank stabilization projects. Riprap was the most common method used to stabilize eroding river banks based on responses to our questionnaire (Figure 2). Riprap with deflectors was the next most common method. Comparatively few projects used methods commonly referred to as fish-and-wildlife friendly (e.g., large woody debris, bioengineering, etc.). Riprap was used to stabilize nearly 55 km of river bank (Figure 3). Although bioengineering methods were infrequently used, they accounted for the second highest length of river bank stabilized (Figure 3). Thus, the areas stabilized using this method appear to be relatively great compared to more conventional methods.

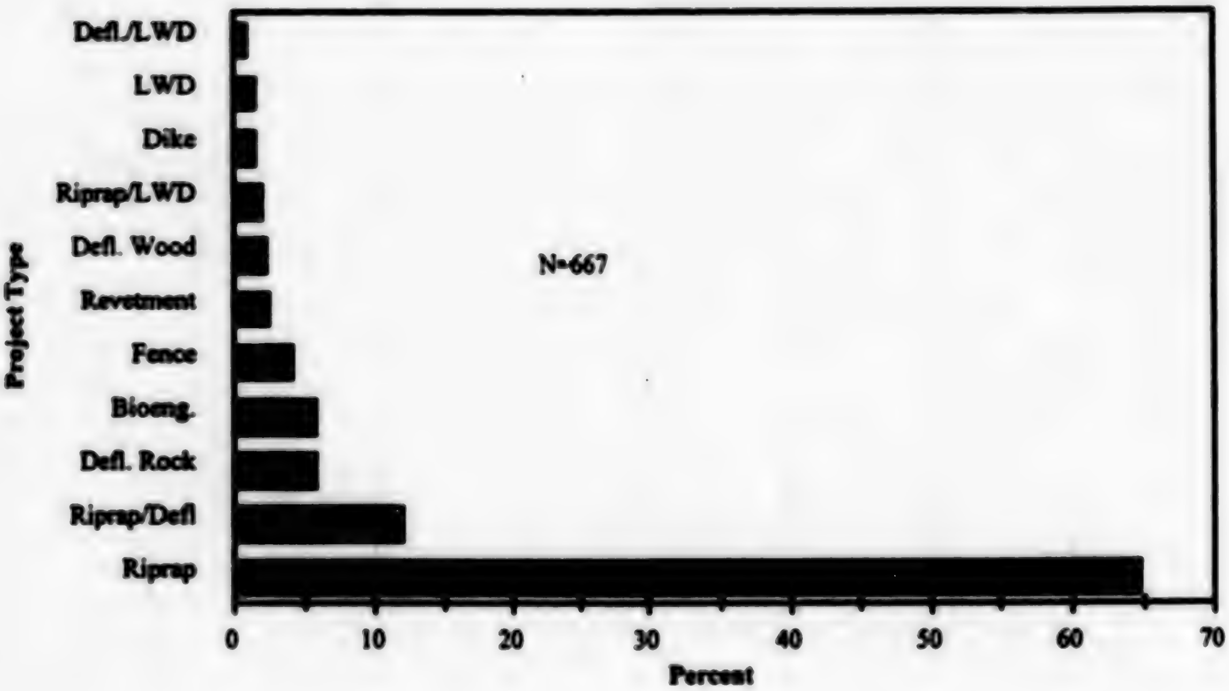

Figure 2. Percent of river banks in western Washington stabilized using different streambank stabilization methods. Results are based on responses to our questionnaire.

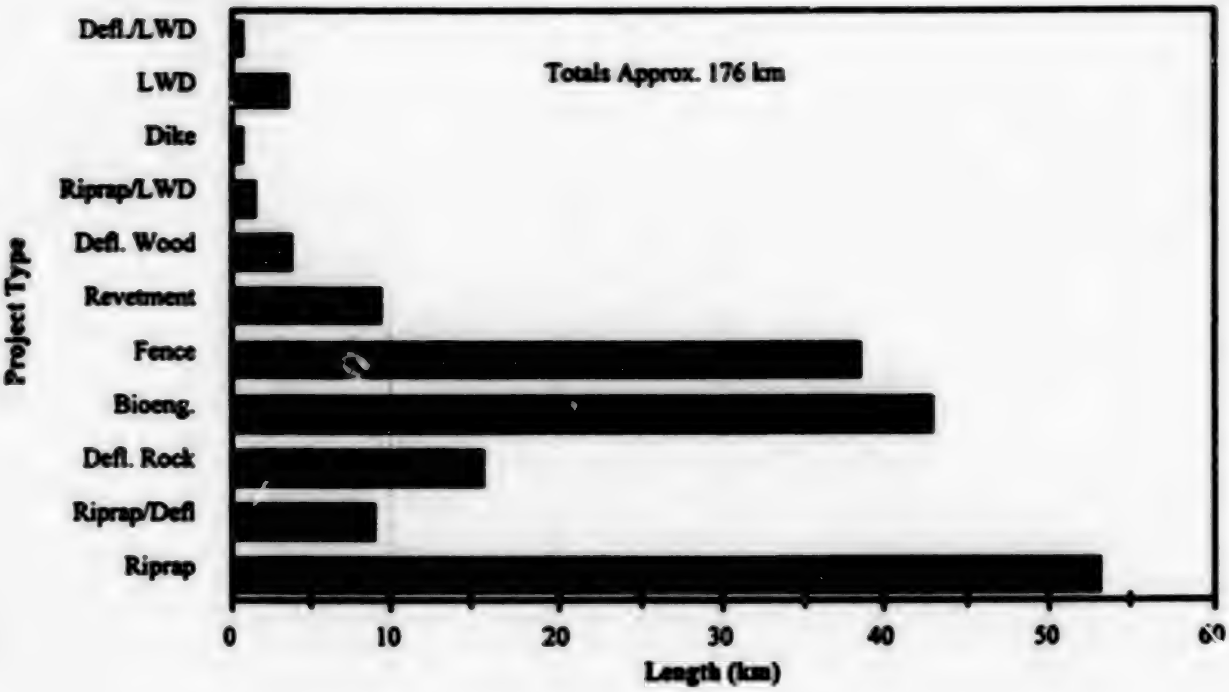

Figure 3. Total length of rivers in western Washington stabilized using different stabilization methods. Results are based on responses to our questionnaire.

Fish Densities at Natural and Stabilized Sites

Stabilized Sites vs. Controls. - LWD projects were the only type of bank stabilization methods that consistently averaged greater fish densities than their control areas for the species and age classes of fish that we examined (Table 3). Average fish densities at sites stabilized with LWD were greater than those observed at their controls during spring, summer, and winter. Riprap-stabilized sites consistently had lower fish densities than the control areas during all seasons. Sites stabilized using deflectors had lower fish densities than their controls in nearly every case during the spring and summer. However, fish densities were generally greater at the deflector-stabilized sites than their controls during the winter. Riprap-with-LWD and combination-stabilized sites were intermediate.

Table 3. Number of comparisons for the fish species and/or size classes of fish that we examined (coho fry, chinook fry, zero-age trout, 1+ trout, 2+ trout, 200+ trout, total juvenile salmonids, and total fish) that had greater mean fish densities at the different bank stabilization sites than their controls.

Season	LWD	Combination	Riprap	Riprap/LWD	Deflector
Spring	7 of 7	3 of 7	1 of 5	3 of 6	1 of 6
Summer	5 of 7	1 of 7	1 of 7	1 of 6	1 of 6
Winter	5 of 6	3 of 6	1 of 6	1 of 6	5 of 6

Although fairly large differences existed in fish densities at certain project types and their controls, these differences were rarely statistically significant (Figure 4). Densities of 1+ trout were greater at LWD sites than their controls (paired t-test: P=0.037), and significantly less at deflectors than their controls (paired t-test: P=0.0098) during spring surveys. Coho fry densities were significantly less at riprap (paired t-test: P=0.0643) and riprap with LWD sites (paired t-test: P=0.0227) than the control areas during the spring. Chinook fry densities were significantly less at riprap sites (paired t-test: P=0.0223) and at deflectors than controls (paired t-test: P=0.0267) during the spring. Total juvenile salmon densities were significantly less at riprap sites than their controls (paired t-test: P=0.0844) during the spring. The power of the paired t-tests was generally low, with only 5 of the 30 tests having power greater than 0.50. Post-test analysis for sample size suggests that sample sizes ranging from 4 to over 1,000 (mean = 172, median = 27) would be required to detect the observed differences 75 percent of the time with 90 percent confidence.

Large differences also existed during the summer. However, only chinook fry densities at riprap (paired t-test: P=0.075) showed significant variation. Lower chinook fry densities were observed at sites stabilized using riprap than at associated control areas. The power of the paired t-tests for the analysis of the summer data was less than 0.5 in all cases. Post-test analysis for sample size suggests that sample sizes ranging from 4 to 900 (mean = 98, median = 32.5) would be required to detect the observed differences 75 percent of the time with 90 percent confidence.

Large differences in fish densities also existed between stabilized sites and their controls during winter. However, these differences again were rarely statistically significant (Figure 5). Three of the six LWD comparisons were statistically significant. Significantly greater densities of salmon fry (t-test: P=0.0457), total juvenile salmonids (t-test: P=0.0114), and total fish (t-test: P=0.0182) were observed at LWD sites than their controls. We also observed statistically more sculpins at combination (t-test: P=0.0089) and riprap (t-test: P=0.0234) bank stabilization sites than their controls. The power of our tests was relatively low (<0.50) for all the non-statistically significant tests. Post-test analysis for sample size suggests that sample sizes ranging from 3 to over 1000 (mean = 125, median = 21) would be required to detect the observed differences 75 percent of the time with 90 percent confidence.

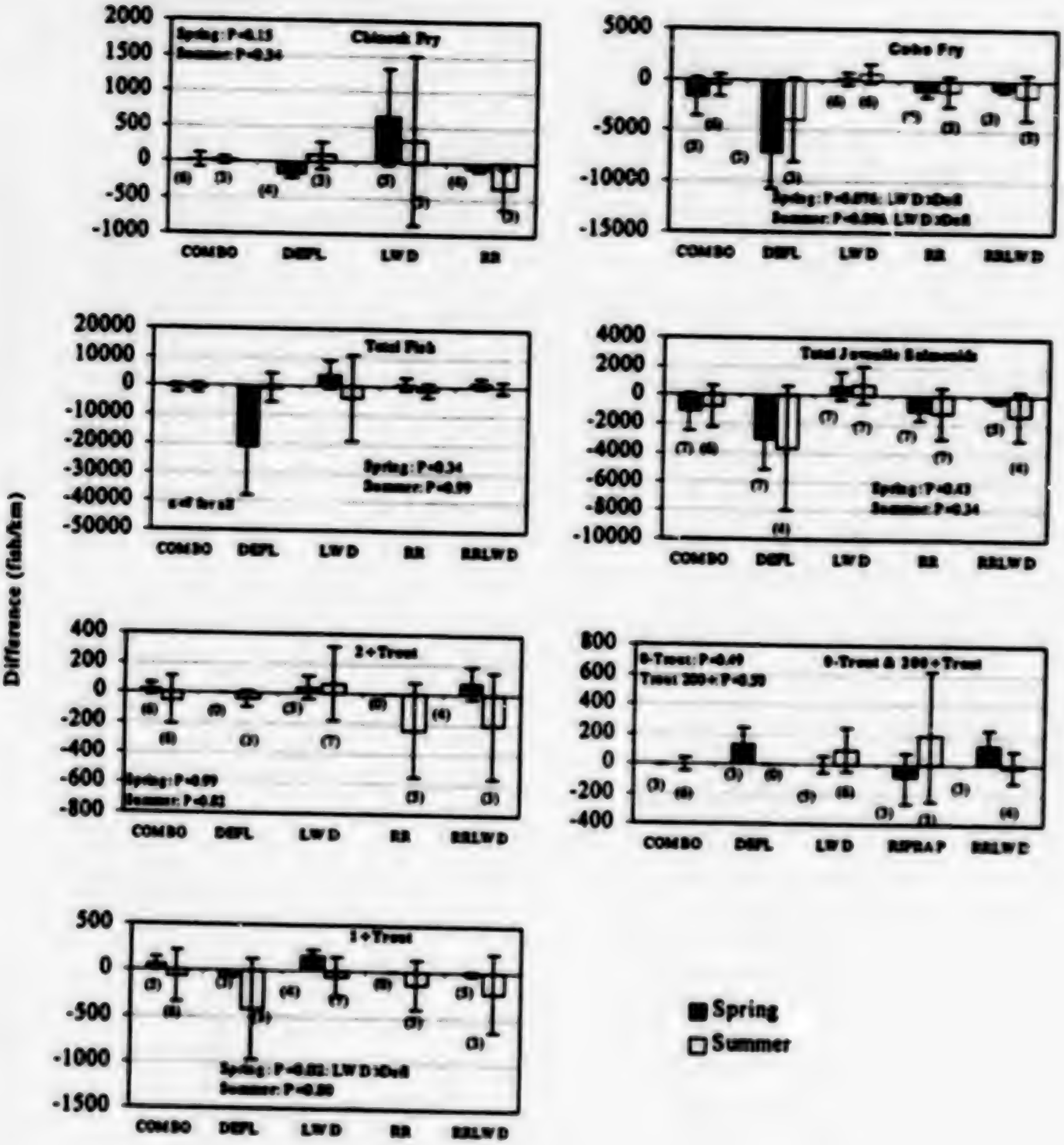

Figure 4. Mean differences observed in the number of chinook fry, coho fry, zero-age trout, 1+ trout, 2+ trout, 200+ trout, total juvenile salmonids, and total fish during the spring and summer 1997. Error bars represent +/- one standard error, numbers in parentheses represent sample size, asterisks (*) denote significant differences (t-test: $P<0.10$) between the project type and their controls, and the *P*-value represents results of the ANOVA.

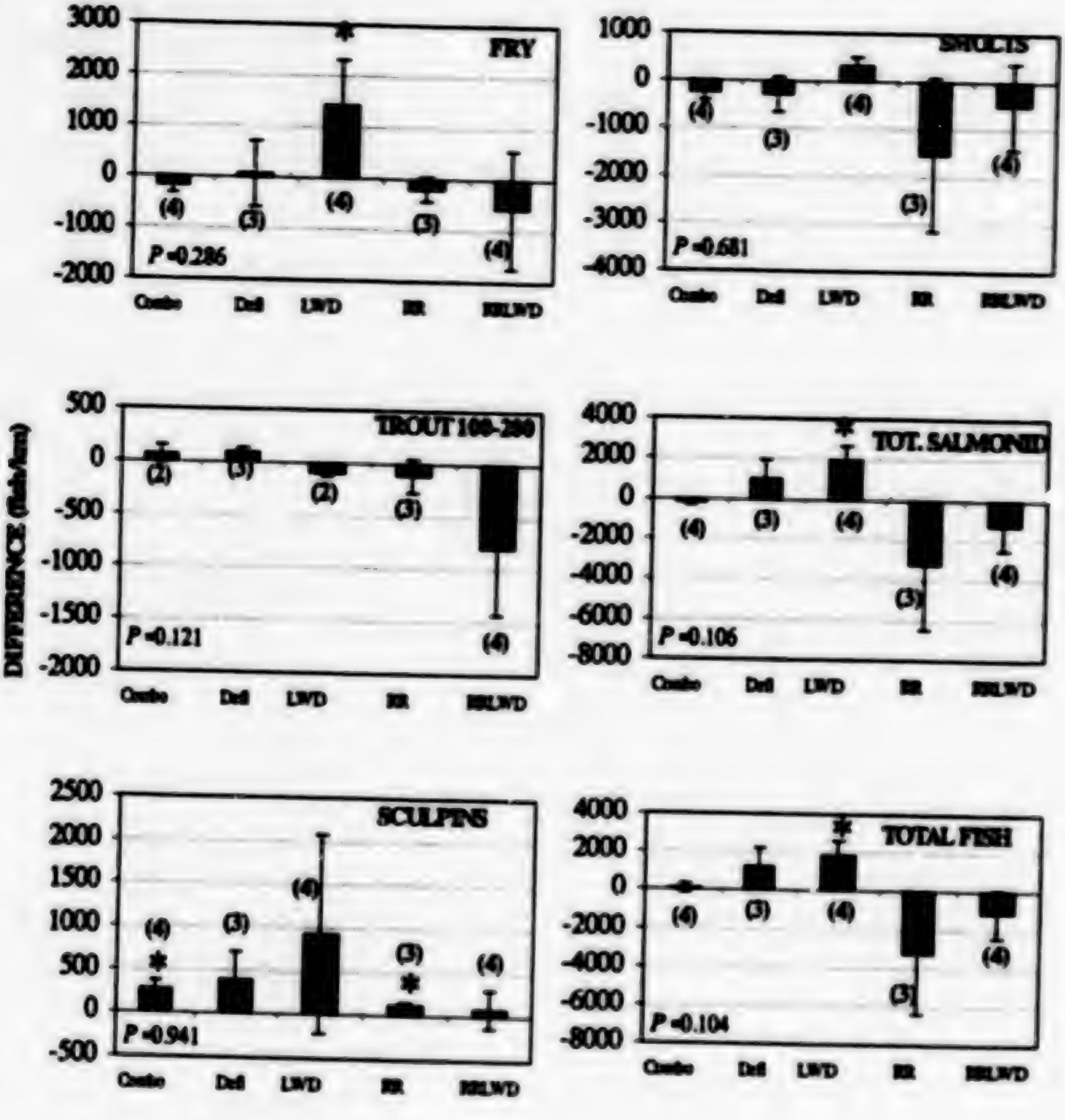

Figure 5. Mean difference observed in the number of salmon fry, salmonid pre-smolts, total juvenile salmonids, 2+ trout, sculpin and total fish between bank stabilization sites and their control areas. Error bars represent +/- one standard error, numbers in parentheses represent sample size, asterisks (*) denote significant differences (t-test: $P<0.10$) between the project type and their controls, and the *P*-value represents results of the ANOVA.

Comparisons of Different Stabilization Methods.- Large differences in fish densities existed among some sites stabilized using different methods during all seasons. However, these differences were rarely statistically significant, which was due in part to high variability of the data (Figures 4 and 5). Coho fry (ANOVA: P=0.0756) and 1+ trout (ANOVA: P=0.0236) were the only species that showed significant differences among project types during the spring (Figure 4). Coho fry (Tukey: P=0.0389) and 1+ trout (Tukey: P=0.0084) densities were significantly greater at LWD sites than deflector sites relative to their control sites. Although no other statistically significant differences existed, greater fish densities of all species were generally associated with LWD-stabilized banks. The power of these statistics was less than 0.3 for all comparisons, except the coho fry (0.35) and 1+ trout comparisons (0.65). Post-test analysis for sample size suggests that sample sizes ranging from 4 to 2,000 (mean = 298, median = 16) would be required to detect the observed differences 75 percent of the time with 90 percent confidence.

Significant differences existed among the different types of bank stabilization projects only for coho salmon (ANOVA: P=0.095) during the summer. More juvenile coho salmon (Tukey: P=0.091) were observed at LWD-stabilized sites relative to their controls than were observed at deflector sites relative to their controls (Figure 4). The power of these tests was less than 0.3 for all comparisons. Post-test analysis for sample size suggests that sample sizes ranging from 7 to 450 (mean = 82, median = 21) would be required to detect the observed differences 75 percent of the time with 90 percent confidence.

No statistically significant differences in fish densities existed among the different project types during the winter, although somewhat large differences were observed (Figure 5). Although not statistically significant, more fish were generally observed at LWD-stabilized sites than any other methods. In contrast to the spring and summer results, where fish densities were generally lowest at deflectors, fish abundance at deflector sites was generally greater than those observed at any other type of projects other than LWD projects (Figure 5).

The low power in our analysis was due to small sample size and large variation. Small sample sizes resulted from the lack of fish being observed at certain study locations during all seasons. Riprap-with-LWD sites were removed from the chinook fry analysis since only two stations remained after all sampling locations that lacked juvenile chinook salmon were removed from the analysis (differences = 80.9 and 30.3 fish/km). After all the locations where 1+ trout were removed from the data set, there were only two riprap sites remaining for the spring analysis (differences = 0 and -90.9 fish/km). Therefore, these two station were eliminated from the analysis. After all the locations that lacked 2+ trout were removed from the data set, there were only two deflector (differences = 20.8 and 14.7 fish/km) and one riprap (difference = 62.5 fish/km) data points remaining for the spring analysis.

Our analyses were again weakened during the summer observations by the fact that many stations lacked salmonid species for comparisons. Deflectors were eliminated from the 200+ trout analysis due to insufficient sample size (differences = -36.3 and -69.0 fish/km). Riprap with LWD was eliminated from the chinook fry (differences =50 and -109.1 fish/km) and dace (differences = 2,900 and 384.6 fish/km) analyses due to insufficient sample size. We eliminated riprap with LWD from the redsided shiner (2,954.5 fish/km) analysis due to insufficient sample size. There was insufficient sample size to complete analyses for zero-age trout during the summer.

We only had to eliminate two station types, combination and LWD, from our winter analyses of 2+ trout. The differences observed among these stations and their controls were 149.2 and -19.6 fish/km for the combination sites, and -130.4 and -82.8 fish/km for the LWD sites.

Test Controls.- Fish densities at the test controls were not significantly different from those at the original controls during spring or summer (Figure 6). The significance levels for these tests were generally above 0.50. Only one significance level was less than 0.5 for the spring (P=0.443, total juvenile salmon) and summer data (P=0.1846, total juvenile salmon). The power of the tests for the spring tests was greater than 0.90 during the spring and 0.90 during the summer.

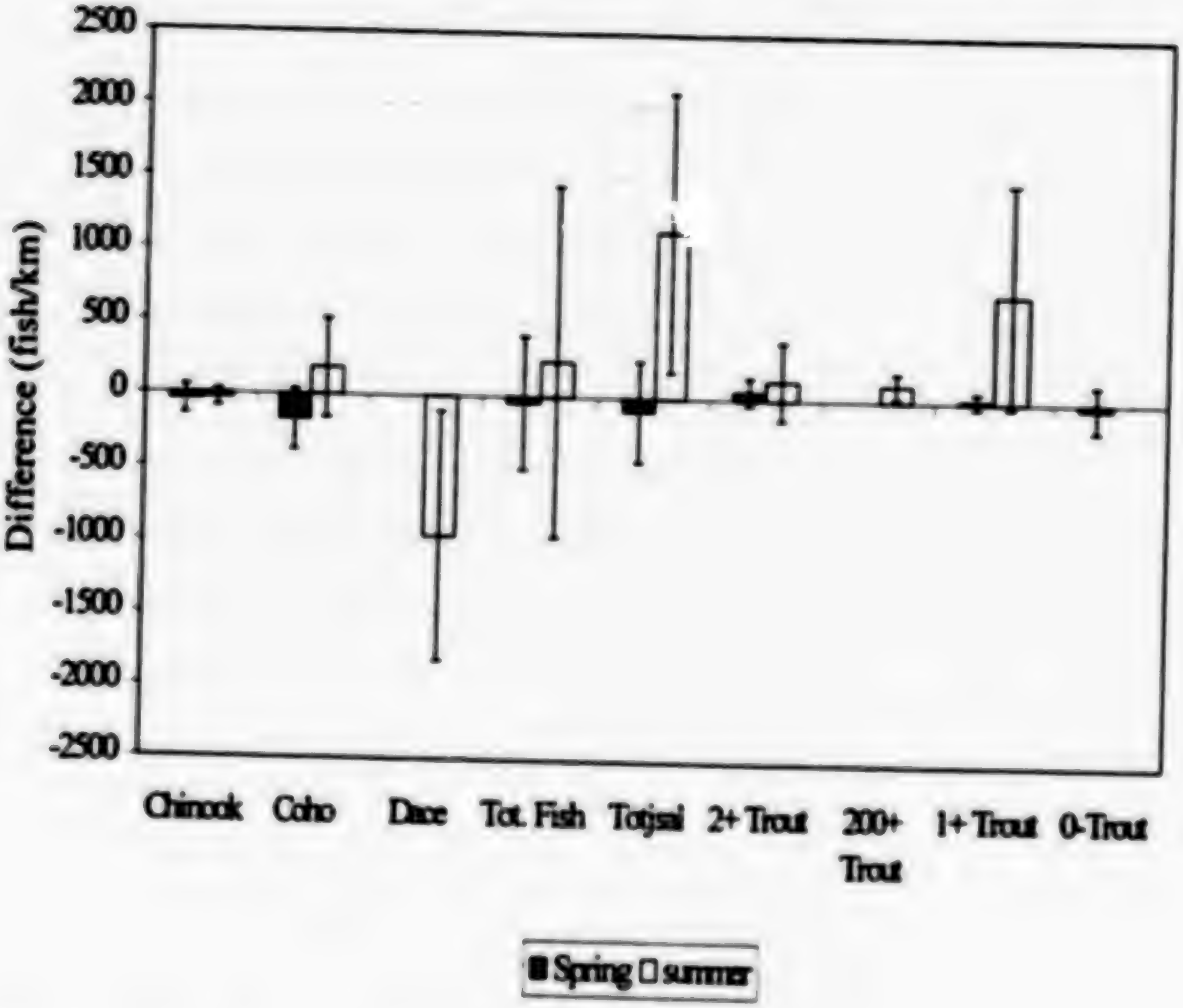

Figure 6. Mean difference in fish densities (fish/km) at test controls and control areas during the spring and summer 1997. Positive values mean there were more fish at the test control than the control. Zero-age trout were present only in the spring sample, and 200+ trout and dace were present only in the summer sample. Totjsal = total juvenile salmonids.

Habitat Differences.- Numerous habitat variables differed significantly among stabilized sites and their controls during all survey periods (Table 4). Variables measuring riparian cover were the most consistent in displaying significant differences. Combination, deflector, and riprap sites had less riparian cover than their controls during the spring and summer. Deflector and riprap sites had less riparian cover than their controls during the winter. Riprap (spring), combination (summer), and deflector (winter) sites had less vegetation overhang than their controls.

Surface area of LWD also differed among stabilized sites and their controls during all survey periods (Table 4). Control areas had greater LWD surface area than riprap sites during spring and summer. Controls also had greater LWD surface area than deflectors during the summer, and riprap with LWD sites during the winter. In contrast, LWD sites had greater LWD surface area than their controls during the winter. None of the remaining variables displayed consistent differences among stabilized sites and controls.

Fish Densities and Habitat Relationships

The differences in numerous habitat variables among stabilized sites and their controls were significantly related to observed differences in fish densities among stabilized sites and their control areas (Table 5). Differences in three habitat variables, percent vegetation overhang, number of areas with different substrate, and percent dominant substrate, were significantly related to differences in fish densities observed at stabilized and control sites during all survey periods. Increased differences in the percent vegetation overhang between stabilized and control sites were associated with increased differences in coho fry densities among these sites during spring and summer. Differences in the density of 2+ trout, 200+ trout, and total juvenile salmonid densities were positively related to differences in percent vegetation overhang during summer. Differences in fry densities among stabilized and control sites increased as the differences in percent vegetation overhang increased during winter surveys.

Although differences in the number of areas with different sediment were related to differences in fish densities among stabilized sites and their controls during all survey periods, the fish species differed with each survey period (Table 5). Differences in coho fry, 1+ trout, and total juvenile salmonid densities were significantly and positively related to differences in the number of area with different substrate found at stabilized and control sites during the spring. Differences in 2+ trout densities were negatively related to the differences in the number of areas with different sediment among stabilized sites and their controls during the summer and winter.

Differences in the percent of the bottom composed of the dominant substrate significantly influenced differences in fish species during all survey periods (Table 5). However, the species influenced changed each survey period. Differences in 2+ trout densities were positively related to differences in the percent of the dominant substrate among stabilized and control sites during the spring. In contrast, differences in zero-age trout densities were negatively related to differences in the percent of dominant substrate among stabilized and control sites during the spring. Differences in coho salmon densities were negatively related to differences in the percent of the dominant substrate among stabilized and control sites during the winter, while differences in dace densities were positively related to this variable. Differences in total fish densities were negatively related to differences in the percent of the dominant substrate among stabilized and control sites during the winter.

Table 4. Physical habitat variables which showed statistically significant variation between different types of bank stabilization projects and their controls during spring, summer, and winter 1997. Significance level (paired t-test), mean, and standard error are also listed. Mean represents the mean difference between the stabilized site and the control (stabilized - control).

Habitat variable	Conclusion	*P*	Mean (SE)
	Spring		
Percent riparian cover	Control > Combo	0.006	-54.3 (13.1)
	Control > Defl	0.005	-54.3 (10.5)
	Control > Riprap	0.038	-35.0 (12.1)
Number of areas with different substrate	Control > Defl	0.002	-1.6 (0.31)
	LWD > Control	0.030	0.78 (0.27)
Percent vegetation overhang	Control > Riprap	0.048	-36.4 (13.9)
Surface area LWD (m^2)	Control > Riprap	0.015	-42.0 (12.1)
Number of pieces of LWD	Control > Defl	<0.0001	-5.1 (0.51)
	Control > Riprap	0.017	-3.3 (0.99)
Number of primary habitats	Combo > Control	0.001	2.86 (0.77)
	Riprap LWD > Control	0.04	1.00 (0.38)
	Summer		
Percent riparian cover	Control > Combo	0.006	-54.3 (13.1)
	Control > Defl	<0.001	-63.3 (6.28)
	Control > Riprap	0.031	-35.0 (12.1)
Embeddedness	Riprap > Control	0.017	1.25 (0.25)
Percent dominant substrate	Defl > Control	0.041	24.9 (9.4)
Percent vegetation overhang	Control > Combo	0.042	-26.2 (9.98)
Total number of undercut banks	Defl > Control	0.018	-1.0 (0.31)
Surface area LWD (m^2)	Control > Defl	0.016	-73.8 (22.0)
	Control > Riprap	0.001	-56.2 (10.4)
Number of pieces of LWD	Control > Riprap	0.005	-2.9 (0.67)
Number of pieces of dense LWD	Control > Riprap	0.036	-1.86 (0.68)
Surface area dense of LWD (m^2)	Control > Riprap	0.049	-35.0 (14.3)
Number of secondary habitats	Combo > Control	0.034	2.3 (0.81)
	Defl > Control	0.011	3.3 (0.92)

Table 4. Continued.

Habitat variable	Conclusion	*P*	Mean (SE)
	Winter		
Surface area LWD (m^2)	LWD > Control Control > Riprap with LWD	0.002 0.023	36.3 (3.58) 41.0 (9.32
Percent riparian cover	Control > Deflectors Control > Riprap	0.004 0.037	26.7 (1.67) 36.7 (6.67)
Flow velocity (ft/s)	LWD > Control	0.035	0.98 (0.25)
Percent vegetation overhang	Control > Deflector	0.027	38.5 (6.03)
Number of undercut banks	Control > Deflectors	0.005	1.17 (0.08)
Length undercut banks (m)	Controls > Deflectors	0.037	3.17 (0.58)
Number secondary habitats	Combination > Controls	0.044	2.0 (0.58)

Table 5. Relationship between differences in fish density observed at different types of bank stabilization projects and their controls, and differences in measured habitat variables during 1997.

Variable	Species	Regression equation	*n*	r^2	*P*
Spring					
Area LWD (m^2)	Coho fry Tot. Juv. Salmonids 1+ Trout	$Y = 0.23x - 21.5$ $Y = 0.24x - 10.8$ $Y = 0.03x + 2.3$	23 33 17	0.72 0.56 0.26	0.0001 0.0001 0.04
Area dense LWD (m^2)	Coho fry Tot. Juv. Salmonids 1+ Trout	$Y=26.6x - 22.6$ $Y = 14.4x - 3.0$ $Y = 4.5x + 3.0$	23 33 17	0.45 0.17 0.29	0.002 0.027 0.03
Number dense LWD	Coho Fry Total Fish Tot . Juv. Salmonids	$Y=12.0x-15.6$ $Y=18.9x-0.8$ $Y=12.8x-4.4$	23 35 33	0.44 0.14 0.40	0.0005 0.03 0.0001
Overhead riparian cover	Chinook	$Y=0.25x+3.17$	19	0.25	0.03
Percent vegetation overhang	Coho Fry	$Y=0.51x - 6.2$	23	0.22	0.025
Number of undercut banks	Zero-age Trout	$Y=4.1x + 5.5$	17	0.30	0.03
Length of undercut banks	Total Fish	$Y=-5.9x - 28.5$	35	0.56	0.03
Number of areas of different sediment	Coho Fry Total Juv Salmonids 1+ Trout	$Y=26.6x - 22.6$ $Y= 14.4x - 3.0$ $Y=4.5x + 3.0$	23 33 17	0.45 0.17 0.29	0.002 0.027 0.03
Percent dominant substrate	2+ Trout Zero-age Trout	$Y= 0.16x + 6.2$ $Y = -0.13x + 4.3$	15 17	0.35 0.27	0.02 0.049
Flow	1+ Trout	$Y = 6.8x + 8.5$	17	0.56	0.01
Number of primary habitats	Coho Fry Total Juv Salmonids 1+ Trout	$Y = 50.4x - 17.1$ $Y = 54.5x - 7.3$ $Y = 11.9x + 5.2$	23 33 17	0.31 0.27 0.31	0.01 0.002 0.02

Table 5. Continued.

Variable	Species	Regression equation	n	r^2	P
		Summer			
Area LWD (m^2)	Coho fry	$Y = 0.15x - 13.6$	23	0.28	0.01
	Tot. Juv. Salmonids	$Y = 0.13x - 13.8$	28	0.16	0.04
	200+ Trout	$Y = 0.04x + 0.79$	21	0.26	0.02
Area dense LWD (m^2)	Coho	$Y = 0.20x - 17.4$	22	0.44	0.001
	Dace	$Y = -0.33\text{-}6x + 7.2$	16	0.40	0.009
	Suckers	$Y = 0.1x + 0.89$	20	0.27	0.02
	Tot. Juv Salmonids	$Y = 0.18x - 17.8$	27	0.27	0.006
	200+ Trout	$Y = 0.04x + 0.28$	21	0.25	0.02
Number dense LWD	Chinook	$Y = 4.6x + 2.2$	14	0.36	0.02
	Redside shiner	$Y = 15.8x + 20.1$	14	0.33	0.03
	Tot. Juv Salmonids	$Y = 9.3x - 10.5$	28	0.18	0.02
	2+ Trout	$Y = 3.9x - 1.9$	24	0.29	0.01
Number LWD	Redsided shiner	$Y = 11.9x + 33.2$	14	0.41	0.01
Overhead riparian cover	Chinook	$Y = 0.24x + 1.8$	14	0.29	0.046
Percent vegetation overhang	Coho Fry	$Y = 0.49x + 4.5$	22	0.25	0.02
	Tot. Juv. Salmonids	$Y = 0.31x + 4.6$	27	0.26	0.007
	2+ Trout	$Y = 0.18x + 1.8$	22	0.32	0.004
	200+ Trout	$Y = 0.13x + 5.6$	21	0.35	0.005
Number of undercut banks	Redsided Shiner	$Y = 57.4x + 43.9$	14	0.60	0.001
Number of areas of different sediment	2+ Trout	$Y = -3.0x - 4.6$	24	0.18	0.04
Percent dominant substrate	Coho	$Y = -0.4x - 4.7$	23	0.24	0.02
	Dace	$Y = 0.09x - 16.3$	19	0.32	0.01
Flow	1+ Trout	$Y = 10.2x - 3.8$	24	0.22	0.02
Ave. depth	Dace	$Y = -68.2x - 5.5$	19	0.32	0.01
	Total Fish	$Y = -63.0x + 0.05$	35	0.20	0.01
	Tot. Juv. Salmonids	$Y = -29.5x - 8.5$	27	0.15	0.049
	1+ Trout	$Y = -16.1x - 2.2$	23	0.29	0.01
Max. depth	Dace	$Y = -55.8x - 4.7$	19	0.29	0.02
	Total Fish	$Y = -38.0x - 4.3$	33	0.13	0.04

Table 5. Continued.

Variable	Species	Regression equation	*n*	r^2	*P*
Embedded score	Dace	Y = 26.1x - 35.8	12	0.53	0.007
	Total Fish	Y = 35.2x - 35.7	20	0.49	0.0004
Number of primary habitats	Coho	Y = 20.5x - 14.6	28	0.28	0.01
	Tot. Juv Salmon	Y = 28.3x - 15.7	28	0.23	0.01
		Winter			
Percent riparian cover	Fry	Y = 0.44x + 8.4	18	0.25	0.03
Number of areas of different sediment	2+ Trout	Y = -21.6x - 13.2	13	0.55	0.004
Percent dominant substrate	Total Fish	Y = -0.59x - 10.6	18	0.25	0.04
Embedded score	Pre-smolts	Y = -13.3x - 4.9	17	0.45	0.003
	Total Fish	Y = -15.1x + 4.7	18	0.26	0.03

A number of the habitat variables we measured significantly influenced fish densities of one species or another during spring, summer, and winter (Table 6). Although many variables were significantly related to fish densities, the relationships explained very little of the overall variation in fish abundance (r^2=0.07-0.27). Of the variables we examined, the measures of LWD most consistently influenced fish densities. Chinook fry, coho fry, and total juvenile salmonid densities were all positively related to LWD surface area, and surface area of dense LWD during the spring (Table 6). Total juvenile salmonid densities were also significantly related to the number of dense LWD pieces present during spring (Table 6). All the juvenile salmonid groups that we examined were positively related to the surface area of dense LWD during the summer (Table 6) and all but 200+ trout were positively related to increasing numbers of dense LWD. Salmon fry were positively related to LWD surface area during the winter (Table 6).

The percent of the site with overhead riparian cover significantly influenced some fish densities during all seasons (Tables 6). Coho fry densities were positively related to increased riparian cover during the spring, while 2+ trout and 200+ trout densities were positively related to increased riparian cover during the winter (Table 6). Salmon fry densities were positively related to increasing riparian cover during the winter (Table 6). The percent vegetation overhang had a significant positive influence on total fish densities during the spring and summer (Table 6).

Table 6. Relationship of fish densities to measured habitat variables at project and control sites surveyed during the spring, summer and winter 1997.

Variable	Species	Regression equation	n	r^2	P
Spring					
Area LWD (m^2)	Chinook fry	$Y = 0.04x + 7.78$	42	0.12	0.02
	Coho fry	$Y = 0.11x + 19.2$	44	0.25	0.001
	Tot. juv. salmon	$Y = 0.12x + 17.7$	64	0.21	0.0001
Number of dense LWD pieces	Tot. juv. salmon	$Y = 5.5x + 18.9$	64	0.15	0.002
Area dense LWD (m^2)	Chinook fry	$Y = 0.04x + 8.9$	42	0.10	0.04
	Coho fry	$Y = 0.12x + 21.4$	44	0.23	0.001
	Tot. juv. salmon	$Y = 0.16x + 20.1$	64	0.27	0.0001
Percent riparian cover	Coho fry	$Y = 0.24x + 19.4$	44	0.15	0.01
Percent vegetation overhang	Total fish	$Y = 0.32x + 41.9$	66	0.07	0.03
Length of undercut banks (m)	2+ Trout	$Y = -0.52x + 7.8$	44	0.09	0.04
Number of areas with different substrate	Tot. juv. salmon	$Y = 7.4x + 8.6$	64	0.10	0.02
Embedded score	Chinook fry	$Y = -2.9x + 19.3$	42	0.13	0.03
	Total fish	$Y = -12.3x + 89.3$	68	0.12	0.005
Flow	Total fish	$Y = -35.2x + 85.4$	68	0.25	0.001
Number primary habitats	Coho fry	$Y = 16.7x + 7.6$	44	0.12	0.02
	Tot. juv. salmon	$Y = 21.4x + 1.6$	64	0.12	0.01
Summer					
Number of dense LWD pieces	Chinook fry	$Y = 1.8x + 1.5$	65	0.16	0.001
	Coho fry	$Y = 5.3x + 12.8$	65	0.11	0.01
	Tot. juv. salmon	$Y = 6.6x + 20.6$	65	0.13	0.003
	2+ Trout	$Y = 2.1x + 6.4$	65	0.13	0.004
	1+ Trout	$Y = 2.9x + 6.8$	65	0.15	0.001
Area dense LWD (m^2) -	Chinook fry	$Y = 0.4x + 2.5$	65	0.13	0.002
	Coho fry	$Y = 0.13x + 15.4$	65	0.14	0.002
	Tot. juv salmon	$Y = 0.17x + 22.5$	65	0.17	0.001
	2+ Trout	$Y = 0.04x + 7.6$	65	0.09	0.01
	200+ Trout	$Y = 0.03x + 3.9$	65	0.15	0.002
	1+ Trout	$Y = 0.7x + 8.0$	65	0.18	0.001
Percent riparian cover	2+ Trout	$Y = 0.1x + 6.4$	67	0.08	0.02
	200+ Trout	$Y = 0.05x + 3.1$	67	0.10	0.01

Table 6. Continued.

Variable	Species	Regression equation	*n*	r^2	*P*
Percent vegetation overhang	Redsided shiner	Y = 0.3x + 9.3	59	0.14	0.003
	Total fish	Y = 0.3x + 56.3	59	0.09	0.03
Flow	1+ Trout	Y = 7.2x + 6.1	68	0.10	0.01
Max. depth	Chinook	Y = 3.3x - 1.2	66	0.07	0.03
Embeddedness	Redsided shiner	Y = -6.3x + 38.8	54	0.09	0.03
Percent dominant subst.	Tot. juv. salmon	Y = 0.2x + 20.7	54	0.09	0.03
	1+ Trout	Y = 0.1x + 7.0	54	0.09	0.03
Number of primary habitats	Coho	Y = 18.0x - 2.1	65	0.15	0.001
	Tot. juv salmon	Y = 18.3x + 6.6	68	0.11	0.005
		Winter			
Area LWD (m^2)	Fry	Y = 0.23x + 13.5	27	0.18	0.03
Percent riparian cover	Fry	Y = 0.25x + 15.7	28	0.15	0.04
Percent dominant subst.	Total fish	Y = -0.03x + 62.4	29	0.19	0.02
	Tot. juv. salmonids	Y = -0.36x + 56.8	29	0.23	0.008

Table 7 summarizes the statistically significant results of comparisons of fish densities at stabilized sites and their controls by species, density differences among stabilized sites and controls, habitat differences among stabilized sites and controls, habitat differences which were significantly correlated with fish differences, and habitat variables that were significantly correlated with fish densities. Of the variables we examined, measures of overhead vegetation and instream woody debris cover were the most consistent variables which could be used to explain the differences observed in fish densities among stabilized sites and their controls. For example, coho salmon densities during the spring were significantly less at riprap-stabilized sites than control sites (Table 7, line 1). These riprap sites had less overhead riparian cover, less vegetation overhang, less surface area of LWD, and fewer pieces of LWD. Differences in coho salmon densities among all stabilized sites and their controls were positively related to differences in percent vegetation overhang, area of LWD, and number of pieces of LWD. Coho salmon densities at all the sites we surveyed were positively related to percent vegetation overhang, and LWD surface area. No other habitat variables that were significantly different among stabilized banks and controls, were also significantly related to both the differences in fish densities observed among controls and stabilized banks and to overall fish densities at all survey sites.

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Table 7. Relationship between observed differences in fish densities among different types of stabilized banks and their control areas, and measured habitat variables which were significantly related to both the differences in fish densities observed among stabilized sites and their controls and overall fish densities at all sites.

Project type	Species	Result (< or > control)	Habitat variables related to differences in fish densities	Habitat variables related to fish densities at all sites
			Spring	
Deflector	Chinook	Less	Riparian cover	
Riprap	Chinook	Less	Percent vegetation overhang	Area LWD
Riprap	Coho	Less	Area LWD Number LWD Percent vegetation overhang	Area LWD Percent vegetation overhang
RR LWD	Coho	Less		
LWD	1+ Trout	Greater	Number of different substrates	
Deflector	1+ Trout	Less	Number of different substrates	
Riprap	Total Juvenile Salmon	Less	Area LWD Number LWD	Area LWD Number LWD
			Summer	
Riprap	Chinook	Less	Number Dense LWD	# Dense LWD Area Dense LWD

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Table 7. Continued.

Project type	Species	Result (< or > control)	Habitat variables related to differences in fish densities	Habitat variables related to fish densities at all sites
			Winter	
LWD	Fry	Greater		Area LWD
LWD	Tot Juvenile Salmon	Greater		
LWD	Total Fish	Greater		
Combo	Sculpins	Greater		
Riprap	Sculpins	Greater		

Discussion

Bank stabilization is a common activity on streams and rivers of the Pacific Northwest, and it can result in significant gains or losses of rearing habitat for juvenile fish. However, the impacts of this activity have received little attention. The impacts of bank stabilization on juvenile salmonids have been shown to differ by season (Knudsen and Dilley 1987), fish species (Knudsen and Dilley 1987), stabilization method (Li et al. 1984), stabilization material (Lister et al. 1995), and with age of bank treatment (Beamer and Henderson 1998). Salmonid densities have generally been found to be lower at stabilized banks than natural river banks (Knudsen and Dilley 1987; Li et al. 1984). However, Lister et al. (1995) found that fish densities were greater at banks stabilized using large riprap (>30 cm median diameter) than natural banks composed of cobble-boulder material. Our results suggest that fish densities are generally lower at stabilized banks except those stabilized using LWD. Different fish species show different responses to bank stabilization and those responses change seasonally.

In general, sub-yearling trout, coho, and chinook salmon rearing densities have been found to be lower at riprap-stabilized banks than natural banks. In contrast, yearling and older trout densities have been shown to be unaffected or increased at riprap-stabilized banks. Knudsen and Dilley (1987) found that coho salmon and young-of-the-year trout (cutthroat and steelhead) were reduced at newly riprapped banks compared to natural banks. Li et al. (1984) found that larval fish densities were lower at continuous riprap revetments compared to natural banks. Chinook were absent from the continuous riprap revetment but were present at spur-dike stabilized sites (Li et al. 1984). In contrast, Li et al. (1984) reported that juvenile cutthroat were absent from spur dikes and present at the continuous riprap revetment. Beamer and Henderson (1998) found that chinook (spring) and coho salmon (late-summer), and sub-yearling rainbow trout (steelhead and resident rainbow) were reduced at riprapped banks compared to natural banks, while yearling and older rainbow trout were apparently unaffected. We found that juvenile salmonid densities were generally lower at riprapped banks than at natural banks during the spring, summer, and winter. However, trout greater than 200 mm in fork length were generally found at greater densities at riprap than natural banks.

Few studies have examined the seasonal impacts of bank stabilization on fish rearing habitat. We found that all juvenile salmonid densities, except zero-age trout and total fish densities, were lower at deflectors during the spring. In contrast, chinook salmon densities were greater at deflectors during the summer. With the exception of pre-smolts, fish densities were greater at deflectors than natural streambanks during the winter. Beamer and Henderson (1998) found that coho salmon and sub-yearling rainbow densities were generally lower at riprapped banks than natural banks during late summer. However, densities of these two groups were not significantly different during the winter.

Different methods and materials influence the impacts of bank stabilization on fish densities. We found that LWD-stabilized banks supported greater coho and 1+ trout densities during the spring than deflectors. Li et al. (1984) found that larval fish densities were greater at spur dikes than continuous riprap revetments. In contrast, we did not see any statistically significant results between deflectors and riprap. The size of rock used in riprapped banks also influences fish densities, with greater fish densities generally associated with larger rock (Beamer and Henderson 1998; Lister et al. 1995).

Many agencies are now requiring or suggesting that LWD be incorporated into bank stabilization projects as mitigation for losses in rearing habitat. We examined two methods, riprap and rock deflectors that had LWD incorporated into them as mitigation. LWD incorporation into continuous revetments did not appear to increase fish rearing densities. Fish densities at combination projects were generally greater than those at rock deflectors, although these differences were not statistically significant. We found that fish densities were positively related to the surface area of LWD at all the sites we snorkeled. Thus, one would have expected that LWD incorporation into these projects would have resulted in increased rearing densities. We feel that the general failure of LWD incorporation into rock revetments and deflectors was due to the poor design and placement of LWD in these projects. The surface area of LWD at riprap revetments was generally less than observed at control areas and generally provided relatively sparse cover. Poor placement of LWD in combination projects, along with the small size and lack of complexity, may have contributed to their relatively poor performance. Most LWD was placed between the rock deflectors. This is a depositional area in low-profile groins that appears to become shallow over time. Thus, these areas often lacked sufficient depth for rearing fish. An additional problem was the placement of the LWD with respect to water depth. A significant proportion of individual LWD pieces were out of the water during summer low flow.

Woody debris appears to be a very important habitat component for juvenile salmonids in larger river channels during spring, summer, and winter. However, this relationship appears to be better developed for chinook and coho salmon fry, and for cutthroat trout than rainbow trout. Coho salmon were absent from areas lacking LWD in the mainstem Clearwater River (Peters 1996). Coho salmon densities were also positively related to increasing LWD surface areas in the mainstem Clearwater (Peters 1996) and Skagit Rivers (Beamer and Henderson 1998). Chinook salmon also clustered near brush or LWD cover (Hillman et al. 1989) and their densities were positively related to LWD surface area (Beamer and Henderson 1998). Lister and Genoe (1970) found that coho salmon were associated with bank cover early in the summer but gradually moved offshore as they grew. Heggeness et al. (1991) found that cutthroat trout (>9 cm) densities were greater in areas of streams containing greater than 40% of the area as overhead or instream cover. We found that chinook and coho salmon, and total juvenile salmonid densities, were positively related to the surface area of LWD during the spring and summer. Coho salmon (Bustard and Narver 1975; McMahon and Hartman 1989) and cutthroat trout (Bustard and Narver 1975) showed preference for areas containing LWD cover during the winter. We found salmonid fry densities were positively related to LWD surface area during the winter.

The relationship between steelhead trout densities and LWD is not as strong as that of chinook and coho salmon. We found that yearling and older trout (steelhead and cutthroat) densities were positively related to increasing surface area of LWD during the summer. We combined cutthroat and steelhead for our study which may have masked the preferences of steelhead trout. Cutthroat trout are generally attracted to LWD cover during the summer (Heggenes et al. 1991). However, contradictory results exist for steelhead trout. Hillman and Chapman (1989) and Baltz et al. (1991) found that juvenile steelhead were rarely associated with woody debris. However, Shirvell (1990) and Swales et al. (1986) found that LWD was an important habitat feature for steelhead parr.

The conclusions of this study depend on two major assumptions. First, snorkel counts provide an accurate and consistent estimate of fish abundance. Second, the control areas we selected are representative of available habitats and represent average fish densities within the reach. Snorkeling has been shown to provide reliable estimates of fish population size in streams and rivers (e.g., Hillman et al. 1992; Zubic and Fraley 1988). However, fish abundance is generally underestimated by 10-50%. Hicks and Watson (1985) used the bounded-count method, which was employed in this study, to account for this underestimation. Numerous factors influence the accuracy of snorkel estimates, including temperature (Hillman et al. 1992), visibility, cover (Rodgers et al. 1992), and fish densities (Hillman et al. 1992). Snorkel estimates of fish densities at controls and stabilized banks were completed under the same environmental conditions with respect to temperature and visibility since both sites were in the same river, and were separated by relatively short distances. Thus, only cover and fish densities could have influenced the consistency and accuracy of our counts. Rodgers et al. (1992) found that counts were more accurate in simple habitats than those with abundant cover. Cover complexity provided by LWD on our snorkel estimates, fish densities were also greater at the control areas than the stabilized banks. Hillman et al. (1992) found that estimates were more accurate when fish were in low densities. Thus, if these factors resulted in errors, we may have underestimated fish densities at control areas relative to the stabilized banks, except at LWD-stabilized sites. Therefore, if errors occurred, the differences observed in this study (reduced densities at all stabilized sites except LWD) would be even greater than stated.

We examined how fish densities at our control sections matched rearing densities within the reach by selecting a second control (test control) and comparing fish densities at the two sites. We found no statistically significant differences between control sections and the test controls. The power of these statistical tests was relatively high (>0.80). Therefore, we feel rearing densities at the controls were representative of those within the reach.

Differences in habitat conditions between bank stabilization sites and their controls could result in differences in fish densities not associated with the bank stabilization project. There were several differences in habitat conditions among stabilized sites and their control areas. However, few differences existed for habitat variables that were significant related to differences in fish densities we observed or to overall fish densities at all the sites we surveyed (Table 7). Many of these habitat differences were also characteristic of the stabilization method and could not be avoided. For example, continuous riprap revetments and many deflector projects lack overhead riparian cover and overhanging vegetation.

We used a conservative alpha level (0.10) for statistical comparisons in this study. We feel this was justified due to the high variability in the data and resulting low power. Most of our statistical tests had power less than 0.30. Thus, there was a 70 percent chance of not rejecting a null hypothesis that fish densities were not significantly different. We felt that by using a conservative alpha level we would help account for this probability.

The authors also would like to point out that the conclusions from this study are drawn from a relatively small sample size (3-4) in some cases. The following recommendations could change as more data is collected. We feel that we have been relatively conservative in drawing our conclusions. For example, total fish densities in the spring were on the average 20,000 fish/km fewer at deflector sites than control sites (n=7). However, the statistical conclusion for this test showed no significant difference. We recommend that caution be used when implementing the following recommendations.

Preliminary Recommendations

Based on our observations to date we recommend the following:

1/ Use LWD to stabilize banks when practical.
2/ Incorporate more and denser (more complex) LWD into riprap- or deflector-stabilized sites. It may be better to have one large component of LWD composed of several logs or rootwads than multiple small components that lack complexity.
3/ Try to place LWD in areas that will maintain depth over time in deflector projects. We recommend placing the LWD within the deflectors themselves where a back eddy would be expected.
4/ Ensure that LWD will be in the water during summer low flow.

What's Next

This report presents the results from the first year of a two-year study. We plan to collect additional data during the summer and winter of 1998/1999. The data from the second year will be combined with the data presented in this report to increase our sample size and statistical power. We have also collected fish and macroinvertebrate community data to assess the impacts of bank stabilization on aquatic ecosystems. We are attempting to develop fish and benthic indices of biotic integrity (Karr 1981; Fore et al. 1996) for large rivers of western Washington. If we are successful, we will use these tools to evaluate the different bank stabilization methods.

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Appendix A: Questionnaire mailed to Federal, State, Tribal, and County agencies, as well as private organizations involved in the completion of bank stabilization work in western Washington.

Questionnaire

Name______________________________ Agency______________________________

Address ____________________________ Phone/FAX___________________________

Project location (county, city/town, stream, township, range, street, etc.):____________________
____

Completion date:______________________

Length of bank stabilization (ft): ________________________

Project goals (i.e., stop erosion, return a natural erosion rate, etc.)________________________
____

Project status (circle one): intact, completely failed, partially failed (give estimates of percent failure)_______

Type of failure (circle one): bank failure (toe erosion, particle erosion, translational slide, slump), plantings failed, structural washout, other ______________________________

Cause of failure if known (e.g., unique hydrologic, hydraulic, or geomorphic condition, etc.)____
____

Bank stabilization/protection method used (circle appropriate responses): toe key, spur dike/rock barb, riprap, turning rocks, rock-filled trenches, live stakes, fascines, brush mattress, brush layers, live cribwall, tree revetment, fencing, other______________________________

Were habitat features included in the project (yes or no, if yes what method, i.e., willow stakes, rootwad placement, woody debris placement, other)?________________________________

What are the primary and secondary land-use activities in the project area (i.e., forestry, agriculture, urban, etc.)? ____

Was the project completed under a "normal" planning process or under an emergency planning process?
____

Was the project completed to repair damage occurring during the 1995-1996 floods? (Circle one): yes, no. If yes did damage exist prior to the 1995-1996 floods? (Circle one): yes, no.

Was the project completed as originally designed? (Yes, No (explain))____________________

Do you have any hydrologic and/or stream habitat data for the project area (yes, no)? If yes, what type?
____

Do you have any pre- or post-stabilization data (e.g., photo points, plan maps, fish/wildlife use, etc.)? (Circle one): yes, no. If yes, what type?______________________________

Appendix B: Comparison of day and night snorkel estimates

Table B.1. Estimated fish densities during day and night surveys in the Wynoochee and Skokomish Rivers during June 1997, and paired t-test results comparing mean day and night density estimates.

	Density (Fish/km)				
Species	Day	Night	*P*	*n*	Power
Chinook fry	107.14 (106.00)	66.88 (107.19)	0.4567	6	<0.5
Coho fry	750.78 (478.18)	832.67 (791.28)	>0.50	7	<0.5
Coho smolts	139.51 (222.33)	121.71 (124.28)	>0.50	4	<0.5
All salmon fry	1,358.29 (722.73)	1,778.43 (2413.85)	>0.50	7	<0.5
0-age trout	282.610 (333.860)	233.509 (437.037)	0.357	7	<0.5
1+ Trout	21.23 (33.02)	36.72 (39.64)	0.4037	5	<0.5
2+ Trout	30.26 (43.34)	40.16 (76.84)	>0.50	5	<0.5
Dace	178.26 (332.93)	93.10 (153.13)	0.2557	4	<0.5
Total fish	1,620.88 (989.46)	2,190.61 (2545.26)	>0.50	7	<0.5
Sculpin	44.01 (31.94)	272.38 (99.37)	<0.0001	7	<0.5

Table B.2. Estimated fish densities during day and night snorkel surveys completed during the winter (1998). Results of the paired t-test, sample size, and power of the test are also provided.

	Density (Fish/km)				
Species	Day	Night	*P*	*n*	Power
Total Fish	1109.84(460.700)	4186.37(980.718)	0.005	14	<0.50
Fry	941.76 (437.504)	1052.38(405.932)	0.456	14	<0.50
Total Salmon	1069.64 (465.152)	3264.42(924.328)	0.034	14	<0.50
Pre- smolts	7.02(4.920)	1446.49(586.796)	<0.001	14	0.90
2+ Trout	39.91 (27.990)	327.46(192.220)	0.056	14	<0.50

END

08-30-99